Remediation Program

RRES

LA-UR-03-1600
June 2003
ER2003-0148
GPP-03-028

Characterization Well R-5 Completion Report

Los Alamos
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Los Alamos NM 87545

Produced by the Groundwater Protection Program, Risk Reduction & Environmental Stewardship Division

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List of Acronyms and Abbreviations

AITH	Array Induction Tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMP	best management practice
CMR	Combinable Magnetic Resonance
CNTG	Compensated Neutron Tool, model G
CVAA	cold vapor atomic absorption
DH	down hole
DOE	Department of Energy (US)
DR	dual rotary
DTH	down-the-hole
ECS	Elemental Capture Spectroscopy
EES	Earth and Environment Sciences (Laboratory division)
EPA	Environmental Protection Agency (US)
ER	Environmental Restoration (Project)
ESH	Environment, Safety and Health
FIP	field implementation plan
FMI	Formation Micro-Imager
FMU	facility management unit
FSF	Field Support Facility (now part of Risk Reduction and Environmental Stewardship)
GPIT	General Purpose Inclinometry Tool
GPS	global positioning system
GR	gamma ray
HASL	Health and Safety Laboratory (US Department of Energy)

HNGS	Hostile Natural Gamma Spectroscopy
hp	horsepower
HSA	hollow-stem auger
IC	ion chromatography
ICPES	inductively coupled plasma emission spectroscopy
ICPMS	inductively coupled plasma mass spectrometry
ID	inner diameter
ISE	ion selective electrode
LANL	Los Alamos National Laboratory
MCFL	Micro Cylindrically Focused Log
MS	mass spectroscopy
msl	mean sea level
NGS	Natural Gamma Spectroscopy
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
OD	outer diameter
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship (Laboratory division)
SGWCC	S. G. Western Construction Company
SSHASP	site-specific health and safety plan
TD	total depth
TLD	Triple detector Litho-Density
UR-DTH	under-reaming down-the-hole (hammer)
WCSF	waste characterization strategy form
WGII	Washington Group International, Inc.
XRD	x-ray diffraction
XRF	x-ray fluorescence

Metric to US Customary Unit Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-5 COMPLETION REPORT

ABSTRACT

Characterization well R-5 was installed by the Los Alamos National Laboratory (LANL or the Laboratory) under implementation of its hydrogeologic work plan, is located on the southern side of lower Pueblo Canyon, about 3000 ft west-northwest of water supply well Otowi-1 and about 4700 ft southeast of the Bayo Canyon Sewage Treatment Plant. The primary purpose of this well is provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding the hydrogeologic setting beneath the Laboratory. In addition, the well was designed to help determine whether Laboratory releases and sewage plant effluents may be present in the regional aquifer beneath lower Pueblo Canyon and, if so, the extent to which contaminants may have affected groundwater quality.

In addition, hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of well R-5 will provide data to evaluate the hydrologic setting in this part of Pueblo Canyon and contribute to implementing a Laboratory-wide groundwater monitoring network. Data from R-5 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

Borehole R-5 was drilled to a total depth of 902 ft using air-rotary drilling methods. No core drilling was conducted. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis. Geologic strata encountered during drilling operations included, in descending order, alluvial sediments, the Guaje Pumice Bed, upper Puye Formation sediments, the Cerros del Rio basalt, the lower section of the Puye Formation, and the intercalcated Santa Fe Group basalts and sediments.

Three possible perched zones were encountered during drilling and geophysical logging. Two possible perched zones above the zone of regional saturation were selected for screen placement. The regional zone of groundwater saturation was encountered at a depth of 685 ft bgs in Santa Fe Group sediments. Water samples for contaminant analysis were collected from the regional aquifer as well as from the upper zones of saturation. Based on the analytical results for five samples taken, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

Well installation, including four screened intervals, was completed on May 31, 2001. The completed well was equipped with a Westbay™ multiport sampling system

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and site completion activities conducted from April 24, to June 21, 2001, at characterization well R-5. The well was installed by the Los Alamos National Laboratory (LANL or the Laboratory) under implementation of its "Hydrogeologic Workplan" (LANL 1998, 59599), is located at the southern end of lower Pueblo Canyon, approximately 3000 ft west-northwest of water supply well Otowi-1 and about 4700 ft southeast of the Bayo Sewage Treatment Plant (Figure 1.0-1). Well R-5 supports the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1996, 70215.1) and was drilled in accordance with the "Task/Site Work Plan for Operable Unit 1049 Los Alamos Canyon and Pueblo Canyon, November 1995" (LANL 1995, 50290.1).

Well R-5 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's former Environmental Restoration (ER) Project, now part of Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing the drilling activities.

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-5. The information presented here was compiled from field reports and activity summaries generated by the Laboratory and the drilling subcontractor. Geophysical data and geodetic survey information are also included. Data from R-5 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

The primary purpose of this well is to provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding the hydrogeologic setting beneath the Laboratory. In addition, the well was designed to help determine whether Laboratory releases and sewage plant effluents may be present in the regional aquifer beneath lower Pueblo Canyon and, if so, the extent to which contaminants may have affected groundwater quality. This well will function primarily to investigate the nature and extent of potential impacts to regional groundwater resulting from Laboratory activities in the Pueblo Canyon watershed. Water-quality, geochemical, hydrologic, and geologic information gathered during drilling and well completion will augment knowledge of regional subsurface characteristics and distribution of any contaminants downgradient of Laboratory releases and sewage plant effluent. These data will be used to update sitewide hydrologic and geologic conceptual models for the Laboratory.

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-5. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data, included as part of previous well completion reports, will be discussed in technical documents to be prepared by the Laboratory.

2.0 PRELIMINARY ACTIVITIES

WGII received contractual authorization to start administrative preparation tasks on January 18, 2001. As part of these tasks, WGII modified existing site-specific health and safety plan (SSHASP) No. 273 to include well R-5 and prepared the R-5 waste characterization strategy form (WCSF). The Laboratory prepared the field implementation plan (FIP), entitled "The Drilling and Testing of LANL Regional Aquifer Characterization Well R-5" (LANL 2001, 71453.1). The FIP specified drilling and sampling plans to guide site personnel in executing R-5 field activities. The host facility, Facility Management Unit (FMU) 80, signed a Facility Tenant Agreement to provide for site access and security control, health and safety, and regulatory and other requirements for drilling and completion activities.

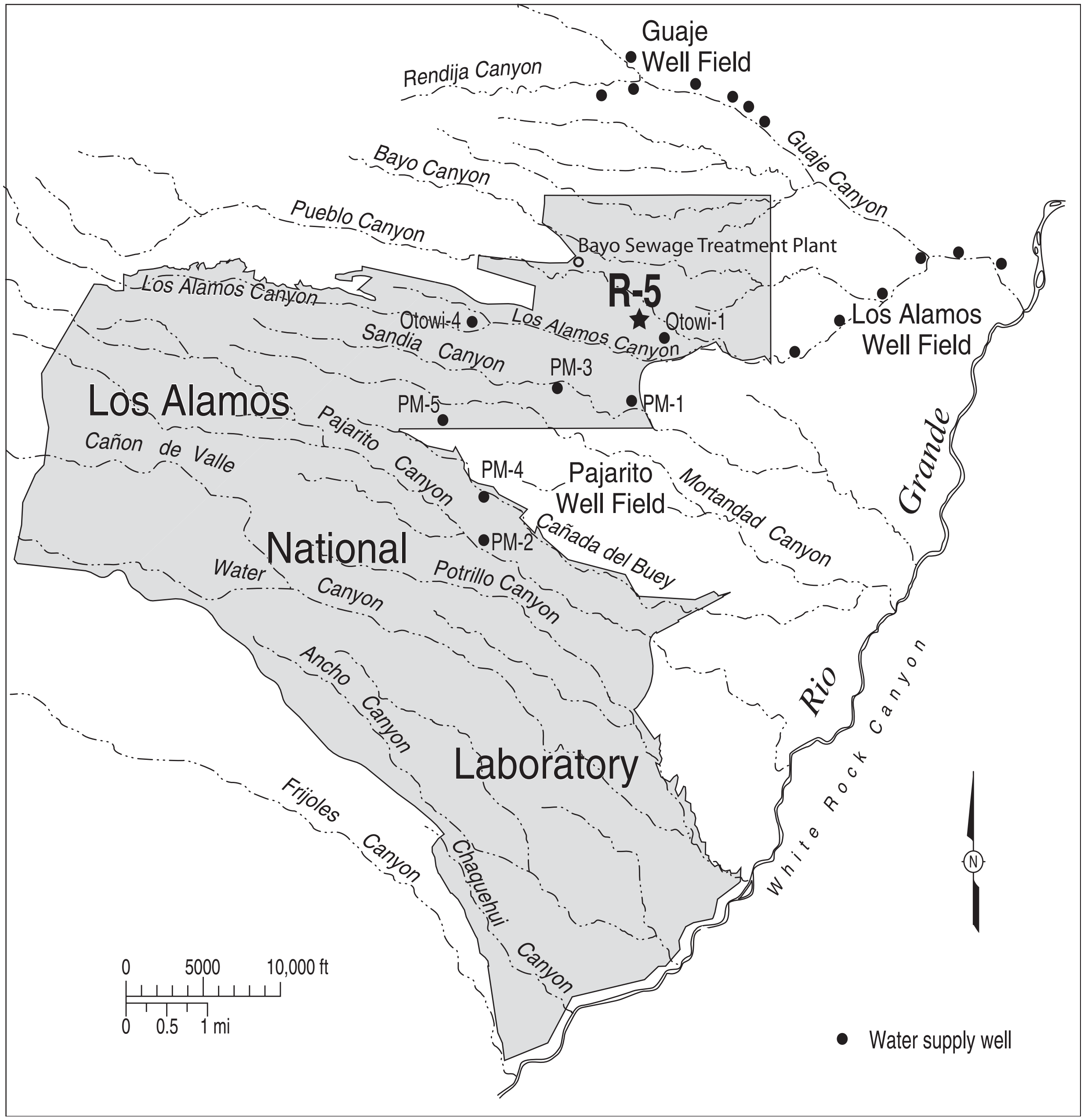


Figure 1.0-1. Location map, characterization well R-5

A readiness review meeting was held on February 2, 2001, to discuss administrative documents, permits, agreements, and plans pertaining to the R-5 project. The Groundwater Investigations Focus Area project leader signed the Phase I readiness review checklist on February 5, 2001, giving authorization to begin fieldwork. The readiness review checklist for Phase II (drilling) was signed on May 5, 2001.

S. G. Western Construction Company (SGWCC) was subcontracted by WGII to perform pre-drilling site preparation. Activities included site clearing, access road construction, drill pad leveling and construction, and excavation for a lined cuttings-containment area. Site preparation, including Phase I drilling, was completed from April 17 through May 1, 2001.

The site initially was cleared of small trees and stumps. An access road was constructed to facilitate mobilization to the well location from the Pueblo Canyon road. The drill pad was constructed by leveling the area with a grader and was completed by grading and compacting several layers (2 to 4 in. each) of base-course gravel. A containment area 6-ft-deep by 20-ft-wide by 60-ft-long was excavated at the south end of the pad to store drilling fluids and cuttings. The containment area was surrounded by a 3-ft-high berm, and the entire excavation was lined with 6-mil polyethylene sheeting. An 80-ft by 25-ft secondary fluids-containment area was constructed to accommodate twelve 3000-gal. polyethylene tanks that would hold drilling fluids pumped from the cuttings-containment area. A berm was constructed around this containment area perimeter and then lined with 6-mil polyethylene sheeting. Safety barriers and signs were installed around the cuttings-containment area and at the site entrance. On April 26, 2001, SGWCC began installation of a jack cellar to assist the dual rotary (DR)-24 rig during drill-casing retraction. The installation was completed on April 27, 2001. Office and supply trailers, safety lighting equipment, and a generator were also set up on the site.

3.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities were conducted in two phases during April and May 2001. Phase I drilling performed by Stewart Brothers Drilling, Inc., involved installing 18-in.-diameter surface casing. Phase II drilling, performed by Dynatec Drilling Company, Inc. (Dynatec), involved installing a jack cellar and drilling a borehole to a total depth (TD) of 902 ft below ground surface (bgs).

Sections 3.1 and 3.2 below discuss Phase I and II drilling activities, respectively. Figure 3.0-1 summarizes well data and depicts groundwater and geologic conditions encountered in well R-5. Figure 3.0-2 summarizes the chronology of drilling and other related on-site activities.

3.1 Phase I Drilling

Phase I drilling was conducted by Stewart Brothers Drilling on April 24 and 25, 2001. A Central Mining Equipment 750 drill rig, owned and operated by Stewart Brothers Drilling and equipped with 20-in. outside diameter (OD) hollow-stem augers (HSA), was used to install 18-in.-diameter surface casing to ensure stability in the upper portion of the borehole. The hole was advanced 36 ft into the upper portion of the Puye fanglomerate. During borehole advancement, auger cuttings were sampled at 5-ft intervals for logging purposes.

Upon removal of the augers, the open-hole depth was measured at 22 ft bgs, indicating 14 ft of slough at the bottom. The surface casing was installed down to 22 ft within the Guaje Pumice Bed. The 18-in.-diameter steel casing was lowered into the borehole and landed at 23 ft bgs. A cement/bentonite grout mixture was pumped into the annulus to form a seal between the borehole and the casing wall from 23 ft to the surface.

3.2 Phase II Drilling

Construction of a jack cellar was completed on April 30,2001, prior to commencement of Phase II drilling. The jack cellar was constructed by excavating an 8-ft by 10-ft by 5-ft-deep pit around the surface casing, placing a 6-ft by 8-ft by 1-ft-thick steel reinforced concrete pad in the bottom of the excavation, placing a temporary steel box (6-ft by 6-ft by 4-ft) on the concrete, and backfilling around the outside of the box. In the event that hydraulic casing jacks would have been needed, the reinforced concrete floor would have provided a solid surface to support the pullback weight of the casing. Upon well completion, the concrete floor was buried in place.

Location: TA-74, Pueblo Canyon

Survey coordinates (brass marker in NW corner of cement pad):
x = 1646707 E   y = 1773063 N (NAD 83)
z = 6472.6 ft asl (NGVD 29)

Drilling: hollow stem auger and fluid-assist air rotary reverse circulation with casing advance
- Phase 1 Start date: 4/24/01
- Phase 1 End date: 4/25/01
- Phase 2 Start date: 5/5/01
- Phase 2 End date: 5/20/01

Borehole R-5 drilled to 902 ft. bgs. (T.D.)

Data collection:
- Hydrologic properties: N/A
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem. and cont. characterization: (4)
- Geologic properties:
  - Mineralogy, petrography, and chemistry (38)
- Borehole logs:
  - Lithologic: 0-902 ft.
  - Video (LANL tool): 570-685 ft
  - Natural gamma (LANL tool): 0-851 ft. (cased), 851-902 ft. (open hole)
  - Schlumberger Logs: 0-851 ft.(cased), 851-898 ft. (open hole): Compensated Thermal and Epithermal Neutron, Spectral Gamma, and Litho-Density

Contaminants Detected in Borehole Samples:
- Regional groundwater: nitrate

Well construction:
- Drilling Completed: 5/20/01
- Contract Geophysics: 5/21/01
- Well Constructed: 5/22/01-5/31/01
- Well Developed: 6/2/01 - 6/21/01
- Westbay Installed: 7/13/01 - 7/19/01

Casing: 4.5-in I.D. stainless steel with external couplings

Number of Screens: 4
4.5-in I.D. pipe based, s.s. wire-wrapped; 0.010-in slot

Screen (perforated pipe interval):
- Screen #1 - 326.4 - 331.5 ft
- Screen #2 - 372.8 - 388.8 ft
- Screen #3 - 676.9 - 720.3 ft
- Screen #4 - 858.7 - 863.7 ft

Well development consisted of brushing, bailing, and pumping.

Groundwater occurrence was determined by recognition of first water produced while drilling. Static water levels were determined after the borehole was rested.

Geologic contacts determined by examination of cuttings, petrography, rock chemistry and interpretation of natural gamma logs.

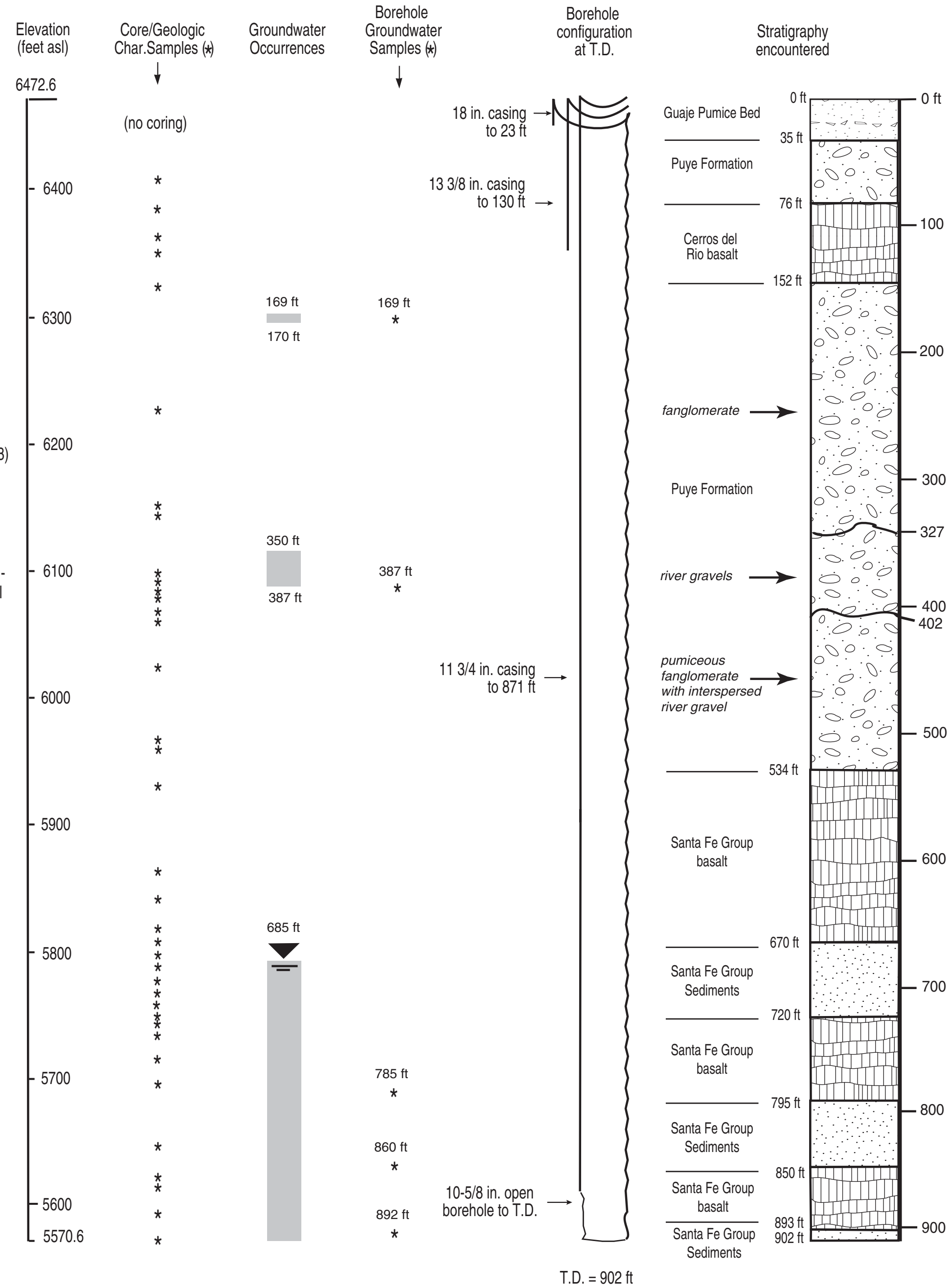


Figure 3.0-1. Well summary data sheet, characterization well R-5

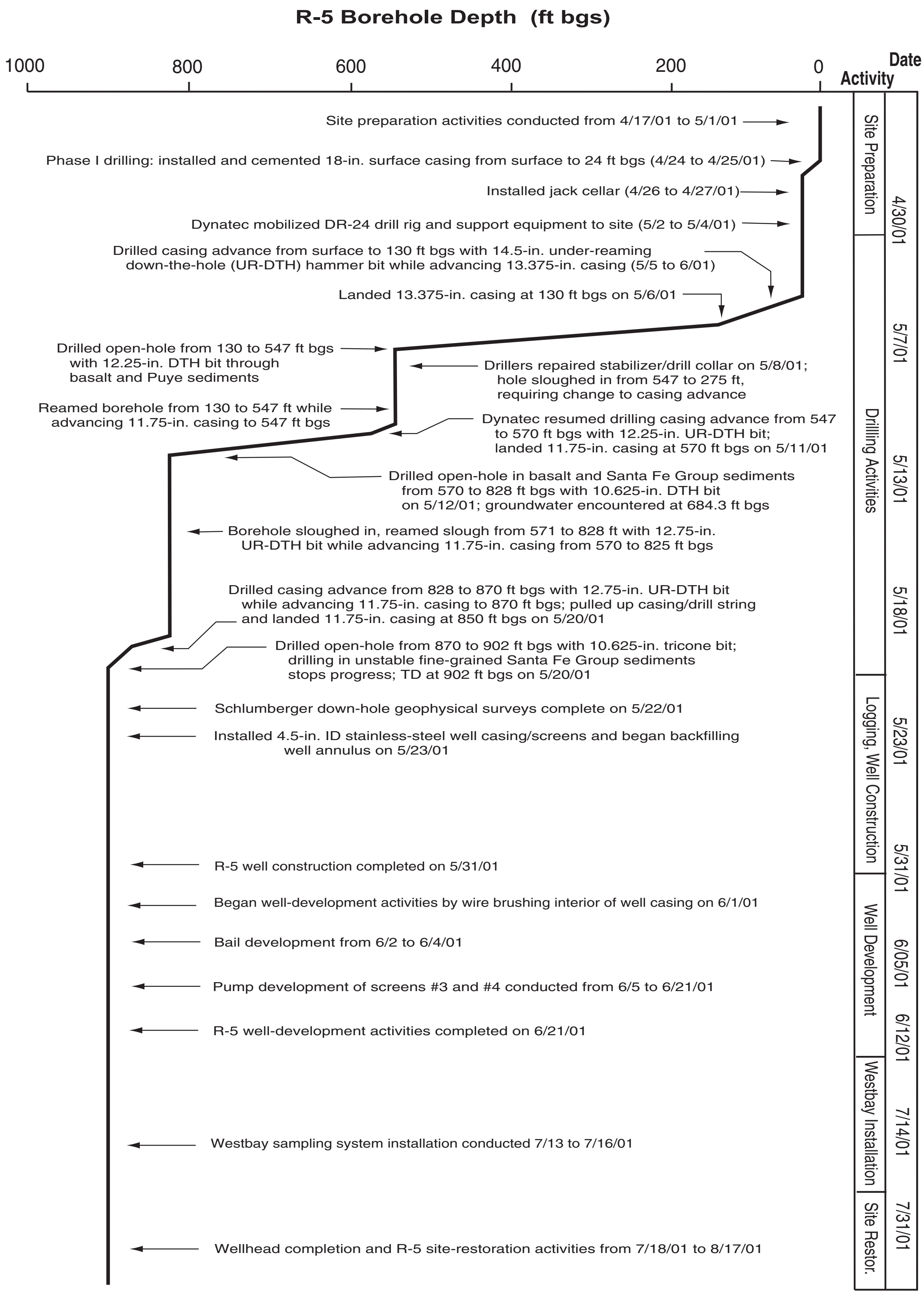


Figure 3.0-2. Operations chronology diagram, characterization well R-5

Phase II drilling was completed between May 2 and May 20, 2001 (Figure 3.0-2), using fluid-assisted reverse-circulation air-rotary drilling methods. Dynatec Drilling Company mobilized a Foremost™ DR-24 drill rig and essential support equipment to the site for Phase II drilling.

Drilling objectives for Phase II were to collect drill cuttings for geologic characterization, collect groundwater samples for contaminant analysis, and provide a deep borehole for geophysical logging and installing of a well in the regional aquifer. Drilling was performed using open-hole and casing-advance methods, as dictated by changing geologic and drilling conditions. Air-rotary drilling was assisted at times with municipal water mixed with polymer additives, such as EZ-MUD™ and QUIK-FOAM™, to improve drilling lubrication and to facilitate cuttings removal from the borehole.

Casing-advance drilling commenced on May 5, 2001, through the Guaje Pumice Bed, the Puye Formation, and into the Cerros del Rio basalt, from approximately 23 to 130 ft bgs using 13.375-in. drill casing with a 14.5-in. under-reaming down-the-hole (UR-DTH) hammer bit. The drill casing was landed in basalt at 130 ft bgs. Open-hole drilling with a 12.25-in. down-the-whole (DTH) bit continued from 130 to 547 ft bgs through Puye fanglomerates and river gravels into Santa Fe Group basalts. Formation instability prompted Dynatec to switch back to casing-advance drilling at 547 ft bgs.

On May 9, 2001, Dynatec tripped in 11.75-in. drill casing to 150 ft bgs, where it encountered slough. The borehole was reamed back down to 547 ft bgs, then drilled to 570 ft bgs with a 12.25-in. DTH bit, where the 11.75-in. casing was landed on May 11, 2001. Dynatec then switched to open-hole drilling using a 10.625-in. DTH bit and advanced the borehole from 570 to 828 ft bgs through basalts and sediments of the Santa Fe Group. Drilling was suspended briefly at a depth of 785 ft bgs to monitor for groundwater.

Unstable borehole conditions were encountered within the Santa Fe deposits, resulting in sloughing of the borehole. Measurements indicated that the borehole depth was 570 ft bgs. Casing-advance drilling resumed on May 15, 2001, by reaming while advancing 11.75-in. drill casing with a 12.25-in. UR-DTH bit from approximately 570 ft. The borehole was re-opened to the previous depth of 828 ft bgs on May 19, 2001. Casing-advance continued to 870 ft bgs. In preparation for a possible call to stop drilling, the 11.75-in. casing was then retracted and landed at 850 ft bgs on May 20, 2001. To provide a viable depth for well sump length relative to desired screen placement, open-hole drilling continued from 870 ft bgs with a 10.625-in. tricone bit. Wet sand and gravel conditions were encountered at 902 ft bgs, and TD of the borehole was called on May 20, 2001.

4.0 SAMPLING AND ANALYSIS OF DRILL CUTTINGS AND GROUNDWATER

During drilling operations at R-5, drill cuttings were collected according to the R-5 FIP. Borehole material was collected as drilling conditions permitted. A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an unsieved portion. These chip trays were studied to determine lithological characteristics and were used to prepare the lithologic logs. The remaining cuttings were sealed in ziplock bags and set in core boxes for curation. No cuttings samples were submitted for contaminant analysis. Prior to curation of the chip trays and cuttings, 38 samples were removed for mineralogic, petrographic, and geochemical analyses. Samples of core were not collected from R-5 and, therefore, not analyzed for contaminants.

During drilling operations, groundwater was encountered in two perched zones and the regional aquifer. Perched groundwater was encountered at approximately 169 ft bgs and between 350 and 387 ft bgs; regional groundwater was first encountered at 685 ft bgs. Groundwater samples were collected from each perched zone (169 and 387 ft bgs) and at three depths in the regional aquifer (785, 860, and 892 ft bgs) and submitted for analysis.

Geochemistry of Sampled Waters

Groundwater samples were collected from the undeveloped borehole during drilling and were analyzed for a limited suite of constituents to investigate the presence of constituents from Laboratory releases and sewage plant discharges (see Appendix A). Major potential contaminants of concern at R-5 include mobile constituents such as perchlorate, nitrate, and tritium. These samples contain residual drilling fluids (EZ-MUD® and other additives) used in the drilling process.

Groundwater samples analyzed for inorganic and radionuclide constituents were collected by air lifting groundwater through the drill stem. Filtered and nonfiltered water samples were collected to analyze metals, trace elements, major cations, and major anion analysis. Nonfiltered water was collected for tritium and radiochemical analyses. Filtered samples were passed through a 0.45-µm Gelman cartridge filter. Samples were acidified as needed with analytical-grade nitric acid to a pH of 2.0 or less for metal and major cation analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed.

Groundwater samples were analyzed by laboratories under contract to the Laboratory using the ER Project statement of work for analytical laboratories (LANL 2000, 71233.1) and at the laboratory of the Earth and Environmental Sciences Division's Hydrology, Geochemistry, and Geology Group (EES-6; within the Laboratory), using techniques specified in the US Environmental Protection Agency (EPA) SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate + nitrite, oxalate, perchlorate, phosphate, and sulfate. Ammonium was analyzed by ion selective electrode (ISE), whereas mercury was analyzed by cold vapor atomic absorption (CVAA). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for aluminum, arsenic, barium, chromium, cobalt, copper, iron, manganese, nickel, selenium, silver, calcium, magnesium, potassium, silica, sodium, and zinc. Antimony, beryllium, cadmium, lead, thallium, vanadium, and uranium, were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). Tritium activity in a groundwater sample was determined by electrolytic enrichment at the University of Miami. Americium-241 was analyzed according to Health and Safety Laboratory-300, cesium-137 by generic gamma spectroscopy, plutonium-238 and plutonium-239 by isotopic plutonium (HASL-300), strontium-90 by beta counting, and uranium-234, uranium-235, and uranium–238 by isotopic uranium (HASL-300). The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPES and ICPMS.

Results of screening analyses for groundwater samples collected from the Puye Formation and Santa Fe Group in R-5 are provided in Table 4.1-1. Based on the analytical results for the five samples, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples, Characterization Well R-5

Analysis	Sample from Puye Formation, 169-ft Depth, May 6, 2001, Filtered	Sample from Puye Formation, 387-ft Depth, May 7, 2001, Filtered	Sample from Santa Fe Group Basalt, 785-ft Depth, May 12, 2003, Nonfiltered with Nitric Acid Digestion	Sample from Santa Fe Group Basalt, 860-ft Depth, May 19, 2003, Filtered	Sample from Santa Fe Group Sediments, 892-ft Depth, May 19, 2003, Filtered
Inorganic Constituents					
pH (field)	—[a]	—	—	—	7.54
Alkalinity (laboratory; mg $CaCO_3$/L)	—	—	—	—	—
Al (mg/L)	—	0.062, J[b]	194	—	—
NH_4 (as N) (mg/L)	0.42	0.90	0.69	—	—
Sb (mg/L)	—	0.0002, J	0.0003, J	—	—
As (mg/L)	—	0.002, J	0.0095	—	—
B (mg/L)	—	0.034, J	0.046	—	—
Ba (mg/L)	—	0.170	1.840	—	—
Be (mg/L)	—	[0.000012], U[c]	0.003	—	—
Br (mg/L)	0.04	[0.02], U	[0.02], U	0.04	0.03
Cd (mg/L)	—	[0.00037], U	0.0012	—	—
Ca (mg/L)	—	28	143	—	—
Cl (mg/L)	5.0	3.3	12.3	5.80	6.17
ClO_4 (mg/L)	0.002	[0.000958], U	[1.6], U	[0.002], U	[0.002], U
Cr (mg/L)	—	0.0018, J	0.151	—	—
Co (mg/L)	—	0.00042, J	0.158	—	—
Cu (mg/L)	—	0.022	0.213	—	—
F (mg/L)	0.71	0.51	0.344	0.21	0.21
Fe (mg/L)	—	0.14, U	268	—	—
Pb (mg/L)	[0.001], U	0.00045, J	0.031	[0.001], U	[0.001], U
Mg (mg/L)	—	3.3	173	—	—
Mn (mg/L)	—	0.012	4.23	—	—
Mo (mg/L)	—	0.0052, J	0.0297, J	—	—
Hg (mg/L)	—	[0.000033], U	[0.0001], U	—	—
Ni (mg/L)	—	0.0055, J	0.577	—	—
NO_3-NO_2 (mg/L) (as N)	0.52	0.48	[0.05], U	0.51	0.48
C_2O_4 (mg/L) (oxalate)	0.64	[0.19], U	0.543, J	[0.02], U	0.72
P (mg/L)	[0.06], U	0.066	—	[0.06], U	[0.06], U
K (mg/L)	—	4.2	16.6	—	—
Se (mg/L)	—	[0.0019], U	0.0045, J	—	—
Ag (mg/L)	—	[0.00057], U	0.0013, UJ	—	—
Na (mg/L)	16.7	13	29.1	—	—
SiO_2 (mg/L)	39.2	64.2	77.9	—	—

Table 4.1-1 (continued)

Analysis	Sample from Puye Formation, 169-ft Depth, May 6, 2001, Filtered	Sample from Puye Formation, 387-ft Depth, May 7, 2001, Filtered	Sample from Santa Fe Group Basalt, 785-ft Depth, May 12, 2003, Nonfiltered with Nitric Acid Digestion	Sample from Santa Fe Group Basalt, 860-ft Depth, May 19, 2003, Filtered	Sample from Santa Fe Group Sediments, 902-ft Depth, May 19, 2003, Filtered
SO_4 (mg/L)	6.17	3.2	11.4	5.18	5.62
Tl (mg/L)	—	[0.00008], U	0.108, J	—	—
U (mg/L)	0.0012	0.004	0.0016	0.0031	0.0023
V (mg/L)	—	0.006, J	0.154	—	—
Zn (mg/L)	—	0.009	0.363	—	—
δD (permil)	—	-76	-66	—	—
D15N (permil)	—	—	—	—	—
D18O (permil)	—	-10.7	-9.9	—	—
Radiological Constituents					
Am^{241} (pCi/L) (nonfiltered)	—	[-0.017], U	[0.0], U	—	—
Cs^{137} (pCi/L) (nonfiltered)	—	[-2.4], U	[0.788], U	—	—
Gross alpha (pCi/L) (nonfiltered)	—	4.1	32	—	—
Gross beta (pCi/L) (nonfiltered)	—	11	57.2	—	—
Gross gamma (pCi/L) (nonfiltered)	—	150	—	—	—
Pu^{238} (pCi/L) (nonfiltered)	—	[0.022], U	[0.009], U	—	—
Pu^{239} (pCi/L) (nonfiltered)	—	[-0.005], U	[-0.0015], U	—	—
Sr^{90} (pCi/L) (nonfiltered)	—	[0.3], U	[0.519], U	—	—
Tritium (pCi/L) (nonfiltered)	—	4.29	—	—	—
U^{234} (pCi/L) (nonfiltered)	—	0.44	19.3	—	—
U^{235} (pCi/L) (nonfiltered)	—	[0.018], U	0.699, J	—	—
U^{238} (pCi/L) (nonfiltered)	—	0.281	16.1	—	—

[a] Dash = not analyzed.

[b] J = the analyte is classified as “detected” but the reported concentration value is expected to be more uncertain then usual.

[c] U = not detected.

5.0 BOREHOLE GEOPHYSICS

The Laboratory and Schlumberger geophysical logging services (Schlumberger) performed borehole logging operations at well R-5. Table 5.0-1 summarizes these surveys.

Table 5.0-1
Borehole and Well Logging Surveys, Characterization Well R-5

Surveyor	Date	Method	Cased Footage	Open-hole Interval (ft bgs)	Remarks
LANL/WGII	May 14, 2001	Video	0–570	570–685	Conducted to evaluate borehole conditions and lithologies.
LANL/WGII	May 20, 2001	Natural gamma	0–850	850–898	Conducted to evaluate borehole conditions and gather data after drilling to 902 ft bgs, prior to well installation.
Schlumberger	May 21, 2001	Logging suite [a]	0–850	850–898	Conducted borehole logging at TD prior to well design and installation.
LANL/WGII	May 23, 2001	Video, caliper	0–884	NA[b]	Conducted in the well casing to assess well construction quality prior to annular backfilling activities.
LANL/WGII	June 1, 2001	Video, natural gamma	0–884	NA	Conducted in the well casing after well construction was completed.

[a] Schlumberger's suite of borehole logging surveys includes lithodensity, spectral gamma, compensated neutron, and natural gamma tool.

[b] NA = Not applicable.

5.1 Geophysical Logging Using Laboratory Tools

Between May 20 and June 1, 2001, natural gamma and video logs were performed in the borehole using Laboratory-provided down-hole tools. The first natural gamma log was collected to obtain lithologic and stratigraphic information that complemented data gathered from cuttings. The first video log was used to assess borehole conditions in the interval from 850 to 898 ft depth. WGII personnel trained to use the down-hole tools performed the logging.

Natural gamma logs have proven successful in discriminating between geologic units that contain varying concentrations of uranium, thorium, and potassium. One natural gamma log was run on May 20, 2001, shortly after drilling to a depth of 902 ft bgs and prior to well installation. Three casing strings lined most of the borehole at that time. The casing in place consisted of an 18-in.-diameter surface casing from ground surface to 24 ft bgs, 13.375-in. drill casing to a depth of 130 ft bgs, and 11.75-in. drill casing to a depth of 850 ft bgs. Open-hole conditions extended from 850 to 898 ft bgs. Slough filled the bottom 4 ft of the borehole. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised upward in the hole at a rate of approximately 15 ft/min.

Video logs were run in the borehole to observe sidewall features and assess the stability of the borehole prior to deploying the natural gamma tool, and to evaluate the open portion of the borehole prior to well installation. The video log of open borehole (Appendix B) appears on a CD attached to the inside back cover of this report. Natural gamma, video, and caliper logging surveys were also performed after R-5 construction activities were completed and run inside the well casing for quality control (QC) purposes to verify proper well construction. Video logs run during well development functioned as a QC procedure to inspect the condition of casing and screens.

5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging in the borehole on May 21, 2001. A suite of logging surveys was performed after achieving the TD of the borehole and prior to well construction. At that time, an 18-in. surface casing extended from ground surface to 24 ft bgs, 13.375-in. drill casing extended from ground surface to 130 ft bgs, and 11.75-in. drill casing was installed inside the outer drill casing from ground surface to 850 ft bgs. The interval between 850 and 898 ft bgs constituted the open portion of the borehole.

The primary purpose of the geophysical logging was to characterize the conditions in the geologic units penetrated by the borehole, with an emphasis on determining moisture distribution, identifying perched groundwater and regional water table zones, and obtaining lithologic and stratigraphic data.

The Schlumberger suite of geophysical logging tools included the following tools:

- Triple detector Litho-Density (TLD™) measures total porosity and bulk density of a formation, photoelectric effects, and borehole diameter and characterizes lithology.
- Natural Gamma Spectroscopy (NGS™) measures overall and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, thus evaluating geology and lithology; and
- Compensated Neutron Tool, model G (CNTG™) measures volumetric water content beyond the casing to evaluate formation moisture content and porosity.

Additionally, a calibrated natural gamma tool was used, and gross natural gamma-ray activity was recorded with every logging method (except NGS™) to correlate depth runs between the surveys conducted. The Schlumberger logging summary report, and the geophysical logs compiled as a montage, can be found in Appendix C on a CD attached to the inside back cover of this report.

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during borehole drilling is presented below. Included is a brief description of the geologic units identified from characterization of cuttings. Groundwater occurrences are discussed based on drilling evidence and geophysical logging data.

6.1 Stratigraphy and Lithologic Logging

A generalized stratigraphic column is shown in the well summary sheet (Figure 3.0-1). Rock units and stratigraphic relationships were determined primarily through visual examination of drill cuttings and analysis of borehole geophysical data logging and should be considered preliminary. These interpretations may be refined upon future detailed analysis of petrographic, geochemical, mineralogical, and geophysical logging data. Appendix D contains a lithology log.

Alluvium and Soil (0 to 20 ft bgs)

Unconsolidated detrital sediments, derived from the Bandelier Tuff, were encountered from the surface to a depth of 20 ft. These pumice-rich sediments represent Quaternary alluvium in the inactive stream channel of Pueblo Canyon. A 1-ft-thick layer of poorly developed soil occurs at the surface. The interval is otherwise made up of abundant vitric pumice fragments, quartz and sanidine crystals, and minor dacite lithics.

Guaje Pumice Bed of the Bandelier Tuff (20 to 35 ft bgs)

The Guaje Pumice Bed of the Otowi member of the Bandelier Tuff is the first bedrock unit penetrated in the interval from 20 to 35 ft bgs. This pumiceous fall deposit forms the basal unit of the Otowi Member of the Quaternary-age Bandelier Tuff. Drill cuttings indicate that the Guaje Pumice Bed is made up almost entirely of nonwelded, vitric rhyolite pumice lapilli that essentially are unaltered. Trace amounts of dacitic lithic fragments also are present.

Upper Puye Formation (35 to 76 ft bgs)

The Pliocene Puye Formation occurs in the interval from 35 to 76 ft bgs. The upper subunit of the Puye Formation is made up of volcaniclastic sand and gravel deposits. The cuttings from this unit are predominantly composed of hornblende- and pyroxene-bearing dacitic clasts that are enclosed in a matrix of silty sand containing grains of volcanic lithics, quartz and sanidine crystals, and local minor occurrences of pumice.

Cerros del Rio Basalt (76 to 152 ft bgs)

The Pliocene Cerros del Rio basalt occurs at 76 to 152 ft bgs. The basalt is sparsely porphyritic with fine-grained olivine phenocrysts in an aphanitic groundmass, with a wide range of vesicularity. Overall, the basalt throughout this interval displays slight alteration represented by local iron-oxide staining and the presence of clay on fracture surfaces and as amygdaloidal fill. A thin layer of glassy basaltic scoria occurs at the base of the basalt.

Lower Puye Formation (152 to 534 ft bgs)

A 382-ft-thick sequence of clastic sediments that form a stratigraphically lower section of the Puye Formation occurs from 152 to 534 ft bgs. These alluvial-fan deposits are dominantly coarse gravels and interlayered sands that are slightly to moderately indurated. Volcaniclastic materials dominate the interval from 152 to 327 ft bgs. The middle half of the section (327 to 402 ft bgs) also contains significant quartzite and plutonic lithologies derived from Precambrian sources. Pumiceous sediments occur in the basal 130 ft of the lower Puye section (approximately 402 to 534 ft bgs).

Upper Santa Fe Group Basalt (534 to 670 ft bgs)

Well R-5 intersected Santa Fe Group basalt flows and scoriaceous breccias from 534 to 670 ft bgs. At least three flow events are evident, each with a basal interval of highly oxidized scoria or basalt cinders. Basalts in this upper sequence of older basalts are aphyric to slightly porphyritic, with phenocrysts of olivine, pyroxene, and minor plagioclase in an aphanitic groundmass. In general, these basalt flows are more altered than those of the younger Cerros del Rio sequence. Evidence of alteration includes reddish iddingsite replacement of olivine phenocrysts, presence of green epidote and/or chlorite, and of green- and orange-colored clay as fragments or as amygdaloidal vesicle fill. The base of the section is marked by the presence of basaltic scoria and pyroclastic cinder clasts.

Santa Fe Group Sediments and Deeper Basalts (670 to 902 ft bgs)

A sequence of Santa Fe Group sedimentary rocks with intercalated basalt flows was encountered from 670 ft bgs to the bottom of the borehole at 902 ft bgs. Characteristics of these units are discussed in the following sections.

Santa Fe Group Sediments

Miocene sandstone of the Santa Fe Group immediately underlies the upper Santa Fe Group basalt, described above, from 670 to 720 ft bgs. Santa Fe gravel and sand deposits, separated by two additional basalt sequences (see below), also are recognized in the intervals from 795 to 850 ft bgs and from 893 to 902 ft bgs. In general, the sedimentary rocks are moderately to well-indurated and contain an abundance of volcanic detritus (dacite, basalt, and pumice) as well as rounded, locally frosted quartz clasts.

Santa Fe Group Basalts

Two additional Miocene basalt units are present in two intervals, from 720 to 795 ft bgs and from 850 to 892 ft bgs. These apparent volcanic flows are intercalated with Santa Fe Group sediments. Both units are porphyritic olivine-bearing basalts that exhibit moderate to very strong secondary alteration. Evidence for rock alteration includes the presence of iddingsite after olivine; amygdaloidal clay, calcite, and zeolite; manganese oxides; chlorite; and local chalcedony. Locally, phenocrysts and groundmass feldspars in these basalts are entirely vacated, resulting in a pitted and vuggy texture evident in chip samples.

6.2 Groundwater Occurrence and Characteristics

Because of its depth and location in Pueblo Canyon, the R-5 borehole was expected to encounter both perched and regional zones of saturation. Two potential perched zones were encountered during drilling in the lower part of the Puye Formation: one at a depth of 169 ft bgs (thickness uncertain) and one between the depths of 373 and 389 ft bgs. A third potential perched zone, between the depths of 325 and 331 ft bgs, was identified through analysis of Schlumberger geophysical data. The regional water table was intersected in sediments of the Santa Fe Group at a depth of approximately 685 ft bgs. The most productive interval in the regional zone of saturation was encountered immediately below a basalt unit in the Santa Fe Group, between a depth of 897 and 902 ft bgs.

Because R-5 was drilled by fluid-assisted methods from 36 ft bgs to TD, saturation was recognized only when highly productive zones were penetrated.

7.0 WELL DESIGN AND CONSTRUCTION

The R-5 well was intended to provide hydrogeologic, geochemical, and water-quality data for the regional groundwater aquifer and for any significant zones of perched water. Sections 7.1 and 7.2 describe the well design and construction, respectively.

7.1 Well Design

The Laboratory, US Department of Energy (DOE), New Mexico Environmental Department (NMED) and WGII participated in the well design. Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Investigations Team to plan screen placement intervals for the well. The number and placement of screens were designed to meet the following criteria:

- to monitor intermediate perched zone(s) of saturation,
- to monitor the top of the regional zone of saturation, and
- to monitor a deeper, more productive zone within the regional aquifer.

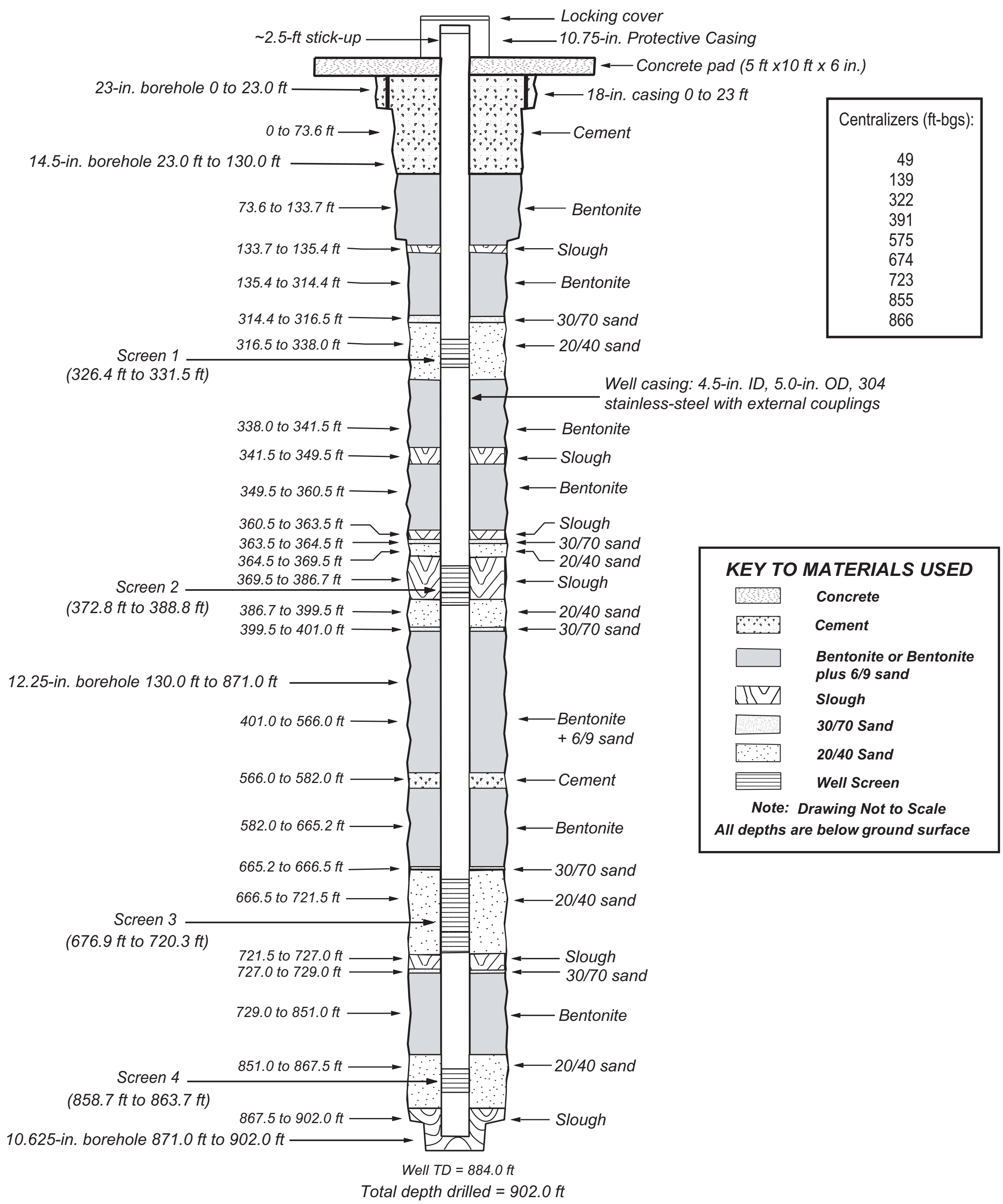
The final design specified four screens for well R-5, consisting of one screen each of the two suspected perched zones in the Puye Formation and two screens in the regional aquifer. The planned and actual screen locations are given in Table 7.1-1. A Westbay™ multiport groundwater sampling system was installed after completion and development of the well.

Table 7.1-1
Summary of Well Screen Information, Characterization Well R-5

Screen	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	329.1–334.1	326.4–331.5	Possible perched saturation zone in the Puye Formation identified from geophysics
2	375.4–391.3	372.8–388.8	Possible saturation zone in the Puye Formation
3	678.9–722.4	676.9–720.3	Top of regional zone of saturation in the Santa Fe Group sediments
4	860.7–865.7	858.7–863.7	Deeper part of regional zone of saturation in Santa Fe Group basalt

7.2 Well Construction

The well casing and pipe-based screens were manufactured using 4.5-in. inner diameter (ID)/ 5.0-in. OD-type 304 stainless-steel fabricated to American Society for Testing and Materials (ASTM) Standard A554. The external couplings used were also type 304 stainless steel fabricated to ASTM Standard A312, which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified from 10-ft sections of blank well casing by drilling a series of 0.5-in.-diameter holes and then welding a stainless-steel wire-wrap (0.010-in. gap) over the perforated interval. The final well screen OD was 5.56 in. The stainless-steel well components were cleaned at the well site using a high-pressure steam cleaner and scrub brushes. The bottom of the well was set at 884.0 ft bgs. All annular fill materials were placed in the borehole well casing annulus through a tremie pipe. Figure 7.2-1 shows the as-built well casing configuration and indicates the depths of the various well components from ground surface.



Notes: 1. The screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.
2. Pipe-based screen: 4.5-in. ID, 5.563-in. OD, 304 stainless-steel with s.s. wire wrap; 0.010-in. slots.
3. The top interval of slough consists of Cerros del Rio sediments. The intervals of slough around screen 2 consist of Puye river gravels. The slough intervals below screens 3 and 4 consist of Santa Fe Group sediments and/or basalt.
4. Westbay multiport sampling system (MP-55) casing not shown.

Figure 7.2-1. As-built configuration diagram, characterization well R-5

7.2.1 Well Installation

Well installation consisted of connecting joints of stainless steel well casing and screen sections by means of threaded couplings in preparation for the installation of the multiport Westbay™ sampling system. Stainless-steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to enhance positional stability during and after backfill placement operations. Dynatec installed the well casing and screen from May 22 to May 23, 2001.

7.2.2 Annular Fill Placement

Placement of annular fill was accomplished by using a steel tremie pipe to deliver annular materials to the specified design depths. Dynatec installed the annular fill material from May 23 to May 31, 2001. Filter packs across screened intervals consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry. Bentonite materials were placed between screened intervals to seal the annular space and prevent interaction between water-bearing zones. Bentonite products also were mixed with municipal water as a fluid slurry. Portland cement (mixed at a ratio of 5 gal. of water per bag of cement) was used to provide foundations for the annular fill (566 to 582 ft) and for wellhead protection in the annular space in the upper 73.6 ft of the borehole.

Table 7.2-1 summarizes the annular fill materials installed during the construction of R-5. The final configuration of the annular materials is also illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials, Characterization Well R-5

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screen intervals	527	bags
30/70 sand (fine-grained)	To separate filter packs from bentonite seals	15	bags
6/9 sand (coarse)	To bridge formation fractures and matrix pores	256	bags
Benseal® (bentonite)	As a high-solids, multipurpose grout	2	bags
Holeplug® (.375-in. angular and unrefined bentonite chips)	To provide a borehole annular seal	354	bags
Pelplug® bentonite (.25 in. by .375 in., refined elliptical pellets)	To provide a borehole annular seal below the water table	229	buckets
Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag)	To provide annular support and surface seal on the upper 100 ft of the borehole	54	bags

*Sand bag = 45 lb ea, bentonite bag/bucket = 50 lb ea, cement bag = 94 lb ea.

8.0 WELL DEVELOPMENT AND HYDROLOGIC TESTING

Well development and hydrologic testing were conducted from June 1 to June 21, 2001. Dynatec performed development procedures, under the supervision of WGII. Activities included wire brushing, well screen swabbing, bailing, and pumping.

8.1 Well Development

Well development was performed in two stages. The initial stage consisted of wire-brushing the well interior, swabbing and surging the screen intervals to draw fine sediment from the constructed filter pack, and bailing to remove unwanted solid materials from the well. In the second stage, a submersible pump was lowered in succession to screens 3 and 4 and on/off cyclic pumping from each water-bearing zone was performed to remove any remaining fines from the filter pack and formation.

Criteria for well development were based on selected field water quality parameters (turbidity, specific conductance, pH, and temperature). To monitor progress during each development stage, groundwater samples were collected periodically and parameter measurements were recorded. One objective of well development was to remove suspended sediment from the water until turbidity, recorded in nephelometric turbidity units (NTU), was measured at a value less than 5 NTU for three consecutive samples. Similarly, the other measured parameters were required to stabilize before development procedures could be terminated. The well was declared sufficiently developed when the above criteria were met, or could not be improved with continued pumping. Table 8.1-1 presents water-quality parameter data measured at the beginning and end of each stage of development method.

Table 8.1-1
Water-Quality Parameter Data, Characterization Well R-5

Method	Water Removed (gal.)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (μS/cm)[b]	Turbidity (NTU)
Bailing screen	3020	6.12–8.00	21.6–19.0	236–216	9.6–482
Pump–screen 3	1095	6.87–8.62	25.5–21.7	235–200	34.2–15.5
Pump–screen 4[c]	985	8.3–8.5	23.4–22.7	230–232	32.7–8.8
Pump–sump	9130	NM[d]	21.5–23.2	130–258	6.7–5.8
Total	**14,230**				

[a] Range is made up of value at beginning, followed by value at end, of the development method; higher and lower values may have been attained during development.
[b] Specific conductance reported in microsiemens per centimeter.
[c] Pumping from screen 4 using 10-hp pump (single packer deployed).

To remove any materials that may have been introduced into the well interior during construction, the casing and screens first were cleaned thoroughly using a wire brush. Preliminary bailing using a 12-gal. steel bailer was performed to remove debris and sediment from the sump. A total of 3020 gal. of water was withdrawn from the well and turbidity was recorded at 482 NTU at the end of bailing (Table 8.1-1).

Pump development procedures were applied to screens 3 and 4 by deploying a single inflatable packer. Complete development procedures were not applied to screens 1 and 2 because of insufficient water production. A 10-horsepower (hp) submersible pump was lowered to each screen and the packer installed above the screen interval. Attempts to develop the screens individually were unsuccessful because the water-bearing zones failed to produce sufficient flow. Then the pump was lowered to the bottom of screen 3, without deploying the packer. A pressure transducer and data logger were installed to continuously measure and record water levels during pumping. The pump was cycled on at a rate of approximately 1 gallon per minute (gpm) withdrawing 1095 gal. of groundwater from the position of the bottom of screen 3. Water samples were collected at regular intervals for parameter measurements. A similar procedure was conducted at screen 4; however, drillers experienced mechanical difficulties with the 10-hp pump that had been positioned below the bottom of the screen. The pumping rate could not be throttled to less than 14 gpm without overloading the circuit breaker, which caused the pump to shutdown. Cyclic pumping was initiated with intermittent periods of down time of up to one hour to allow water level recovery. A total of 985 gal. of water was purged, and turbidity was recorded at 8.8 NTU by the end of the pumping period (Table 8.1-1).

Pump development was resumed after a 7.5-hp submersible pump was installed below screen 4. Three periods of on/off cyclic pumping were performed with a pressure transducer and data logger installed to measure the water-level response. Pumping was conducted at flow rates that varied from 10.5 to 2.8 gpm. Two additional pumping periods were performed without the transducer/data logger system. Turbidity was less than 6 NTU at this final stage of well development (Table 8.1-1).

Figure 8.1-1 compares the variation in measured field parameters with gallons of water purged during pump development. The graph shows that specific conductance and temperature were reasonably stable during the latter period of pumping and that turbidity had fallen below 6 NTU when R-5 was declared fully developed.

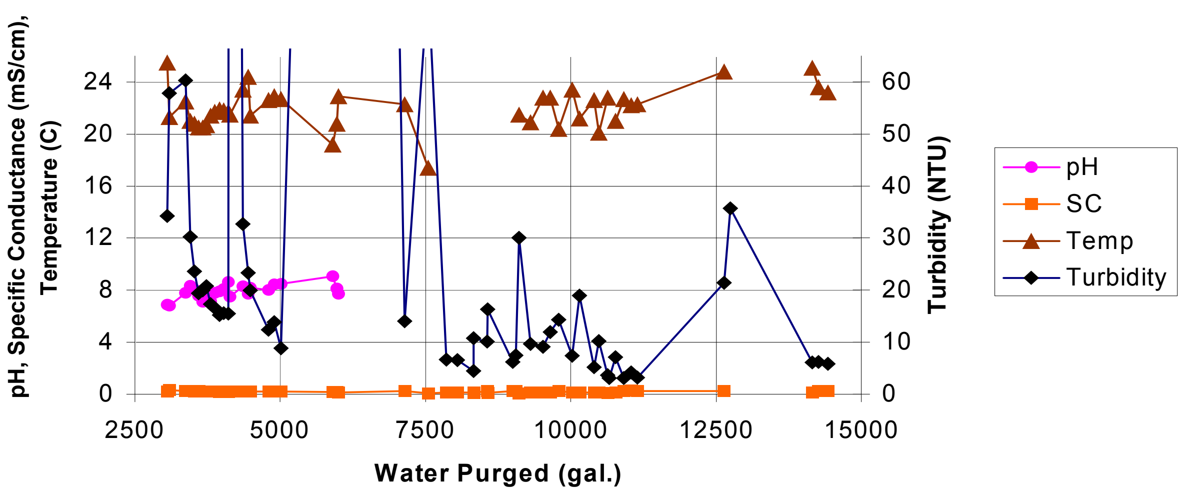


Figure 8.1-1. Effects of pump development on water-quality parameters, characterization well R-5

8.2 Hydrologic Testing

Hydraulic properties of saturated materials in multiscreened R-wells normally are evaluated by straddle-packer/injection tests. However, such testing was not appropriate for two of the four screens in R-5. Material behind screen 1, targeting a suspected perched zone of saturation, was dry, and screen 3 straddles the regional water table. The method cannot be used in these conditions because injected water would drain quickly from the well into the unsaturated geologic media, leading to an overestimate of permeability (Fetter 1994, 70942). Although materials behind screens 2 and 4 were wet, they were not productive. In view of the fact that the pump in the straddle-packer/pump assembly used for development of these intervals kept shutting off because of a lack of water, they were not tested.

8.3 Installation of Westbay™ Monitoring System

After development procedures in well R-5 were completed, a Westbay™ multiport sampling system was installed inside the stainless steel well casing. The Westbay™ multilevel sampling diagram provides construction details of the installed system (Appendix E).

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

When operational tests were completed on the installed sampling system, the protective casing height was adjusted to accommodate a locking cap over the Westbay™ installation. Finish work commenced on the wellhead area, well components were surveyed, and the site underwent final clean up and restoration.

9.1 Wellhead Completion

The surface completion involved placement of a reinforced (5000 pounds per square inch [psi]) concrete pad, 5-ft by 10-ft by 12-in. thick, around the well casing to ensure the long-term structural integrity of the well (Figure 9.1-1). The concrete pad was placed on August 15, 2001. A 3-in.-diameter threaded galvanized-steel conduit approximately 18 in. long with a 12-in. stickup was embedded vertically through the pad to allow for future installation of a solar-power energy supply. A 10.0-in. steel protective casing with a mushroom cap protects the well riser. Four 4-in.-diameter concrete-filled steel bollards were placed at each side of the pad boundary. One bollard is removable to allow access to the well for sampling and maintenance activities. A brass survey pin was installed in the northwest corner of the concrete pad.

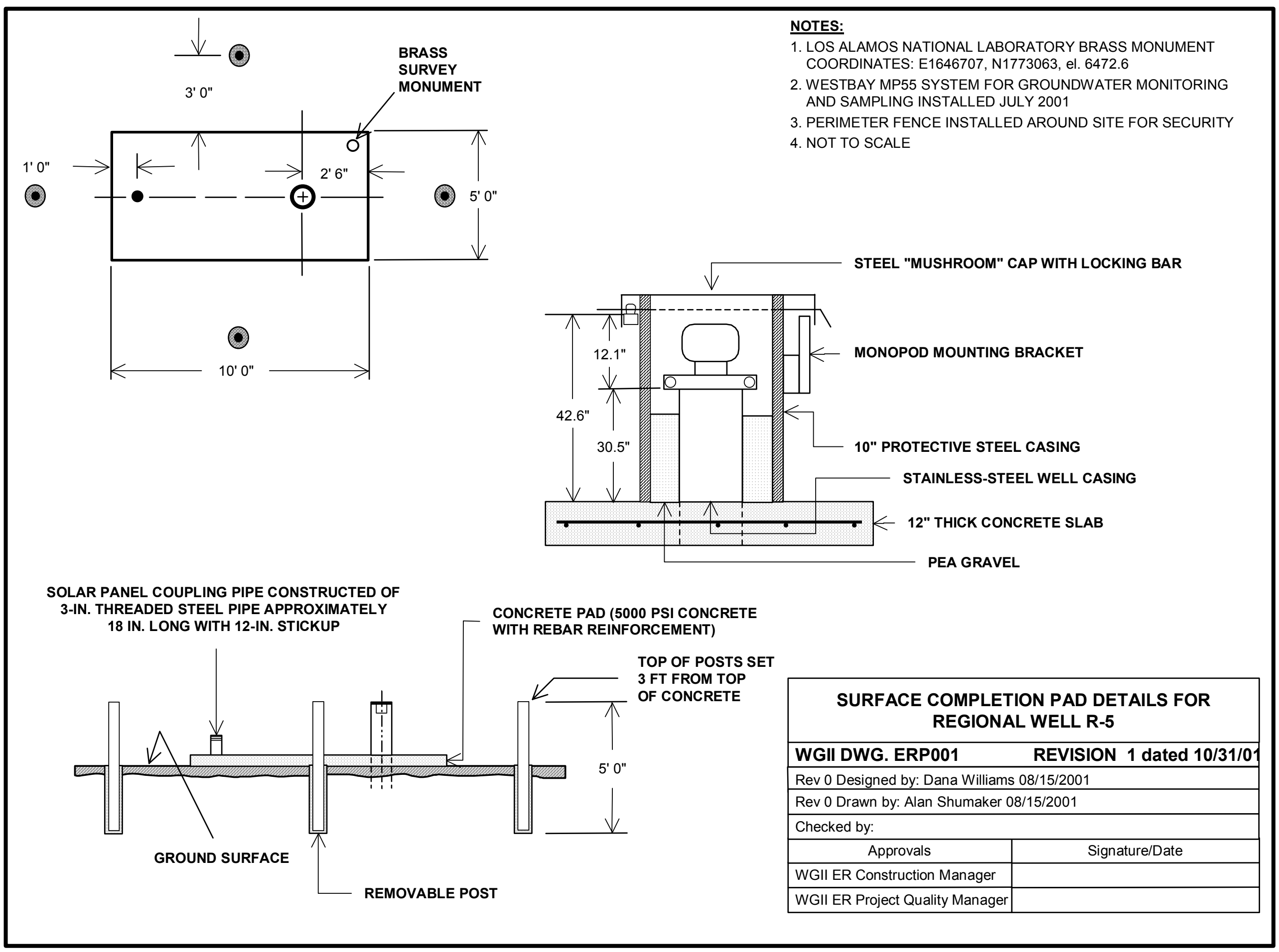


Figure 9.1-1. Surface completion configuration diagram, characterization well R-5

9.2 Geodetic Survey

The location of R-5 was determined by geodetic survey on September 5, 2001, using a Wild/Lesca TC 1000, 3-Second Theodolite total station. Control for the survey was provided by control points B0001 and 74-16 from the 1992 Laboratory-wide control network. Field measurements were reduced using LisCad Plus® surveying software.

The survey located the brass cap monument in the northwest corner of the concrete pad and measured elevations to the top of the steel protective casing, top of the Westbay™ collar, and top of the Westbay™ plate at R-5 (Table 9.2-1). Horizontal well coordinates are in the New Mexico State Plane Coordinate System, Central Zone (North American Datum, 1983 [NAD 83]), expressed in ft. Elevation is expressed in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

Table 9.2-1
Geodetic Data, Characterization Well R-5

Description	East Coordinate	North Coordinate	Elevation ft*
Top of steel protective casing (north edge)	1646709	1773061	6475.7
Top of Westbay™ Collar	1646709	1773061	6475.5
Top of Westbay™ Plate	1646709	1773061	6475.0
Brass cap in R-5 pad	1646707	1773063	6472.6

* Measured in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

The Facility for Information Management, Analysis and Display (FIMAD) location identification number for the R-5 well is PU-10177.

9.3 Site Restoration

From July 18 to August 17, 2001, site restoration activities were completed. Prior to recontouring, the cuttings-containment area was excavated and the plastic lining removed. Then the containment area was backfilled with dirt that had been bermed during pad construction. The water storage tank trailers were removed, and the secondary containment area was cleaned up, and the drill site area was recontoured to conform to the surrounding topography. The base-course area was reduced in size and regraded up to and around the concrete wellhead pad to promote drainage. In addition, the site was cleared of the brush piles that had accumulated during tree removal activities related to drill pad construction.

The straw wattles and silt fences that are part of the R-5 site best management practices (BMPs) remain in place as needed. The site was re-seeded with a Laboratory-provided blend of native grasses mixed with straw mulch to facilitate reintroduction of ground cover. Site restoration activities after drilling was completed were conducted.

10.0 DEVIATIONS FROM THE R-5 FIP

Appendix A compares the actual characterization activities performed at R-5 with the planned activities in the hydrogeologic work plan and the R-5 FIP. Significant deviations are discussed below:

- *Planned depth.* The FIP stated that the approximate depth of the boring would be 1200 ft bgs. The actual depth of the borehole was terminated at a depth of 902 ft bgs because unstable Santa

Fe Group sediments were encountered. The boring had been advanced 217 ft into the regional aquifer, which was consistent with the work plan.

- *Number of core/cuttings samples collected for contaminant analysis*. Collection of sidewall cores was not possible because 11.75-in. casing was advanced during drilling to a depth of 870 ft. Additionally, the lack of any contaminants of concern in the screening water samples collected from the perched zone and regional aquifer precluded the usefulness of submitting cuttings samples for contaminant analyses.

- *Field hydraulic property tests.* Straddle-packer/injection tests were not conducted at this location because the screen intervals were dry or nonproductive or a screen interval straddled the water table.

11.0 ACKNOWLEDGEMENTS

Dynatec Drilling Company provided the rotary drilling services under the direction of John Eddy.

D. Thompson and C. Schultz of PMC Technologies, Exton, PA; R. Lawrence, P. Schuh, and E. Tow of Tetra-Tech EM, Inc., Albuquerque, NM; contributed to the preparation of this report.

D. Broxton, A. Groffman, S. Pearson, W. Stone, and D. Vaniman, of Los Alamos National Laboratory, prepared this report.

R. Bohn and E. Louderbough, of Los Alamos National Laboratory, reviewed this report for classification and legal purposes, respectively.

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Appendix A

Activities Planned for R-5 Compared with Work Performed

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Planned Depth	100 to 500 ft bgs into the regional aquifer	Approximately 1200 ft bgs	Total drill depth 902 ft bgs, approximately 217 ft bgs below the regional water table
Drilling Method	Methods may include, but are not limited to hollow-stem auger (HSA), air-rotary/Odex/Stratex, air rotary/Barber rig, and mud-rotary drilling	HSA and casing-advance/open-hole, air-rotary equipment	HSA and casing-advance/open-hole, air-rotary equipment
Amount of Core	10% of the borehole	No core planned	No core attempted
Lithologic Log	Log to be prepared from core, cuttings, and drilling performance	Log to be prepared from cuttings, geophysical logs and drilling performance	Log prepared from cuttings, geophysical logs, and drilling performance
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	Up to three water samples will be collected and will target perched zones and the regional aquifer. The geochemistry project leader and technical team will determine the number and locations of samples based on conditions encountered. The number of sampling events after well completion is not specified.	Four water samples were obtained. Water was collected from two perched zones at 169 ft bgs and 387 ft bgs. Water from the regional aquifer was sampled at 860 ft bgs and 892 ft bgs.
Water Sample Analysis	Initial sampling: Radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, VOCs, and metals. Saturated zones: radionuclides (tritium, ^{90}Sr, ^{137}Cs, ^{241}Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Anions (dissolved), major cations, trace elements and metals (dissolved), ^{90}Sr (dissolved), tritium (low level or direct counting), RVGross alpha, beta and RVGross gamma, NH_4, NO_3, NO_2, Br^1, Cl^{-1}, PO_4, F^1, SO_4, Stable isotopes ($^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$, CLO_4^-)	^{241}AM, Gamma spec, isotopic Pu, isotopic U, ^{90}Sr, stable isotopes (deuterium, $^{18}O/^{16}O$), total uranium by ICPMS, cation by MS, anions, gross alpha, beta, and gamma, low-lev tritium, TAL-metals +Fr +B+Mo+Si+Sr, NO_3, NO_2, NH_4, anions, Radvan, and Semi VOAGCMS
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole	Up to two cuttings samples will be selected for geochemical and contaminant characterization by the geochemistry task leader during drilling operations.	No core or cuttings samples submitted for contaminant analysis. Collection of sidewall core was not possible because of drill casing in the hole from 0 to 870 ft.

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Cuttings/Core Sample Analytes	Upper-most sample to be analyzed for a full range of compounds; deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low- and high-detection levels), and metals. Four samples to be analyzed for VOCs.	Cuttings analyses may include radionuclides, metals, and anions. Each sidewall core sample shall be analyzed for the following anions: boron, bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate.	No core obtained
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	No laboratory hydraulic property tests planned	No samples submitted
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses.	The geology task leader will determine the number of samples analyzed for characterization. Testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, by electron microprobe, by scanning electron microscope, and geochemistry by XRF.	Thirty-eight samples were characterized for mineralogy, petrography, and rock chemistry.
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	In general, open-hole geophysics includes caliper, array induction imager, triple lithodensity, full-bore formation microimager, combinable magnetic resonance tool, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron log, mechanical sidewall coring, and elemental capture spectrometer. In general, cased-hole geophysics includes: triple lithodensity, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron and elemental capture spectrometer	Video (LANL tool): 570 – 685 ft bgs, natural gamma (LANL tool): cased 0–851 ft bgs, and open hole 851–898 ft bgs, Schlumberger geophysics (0-851 ft bgs cased, 851–898 ft bgs open hole): lithodensity, spectral gamma, compensated thermal/epithermal neutron
Water-Level Measurements	Procedures and methods not specified in hydrogeologic work plan	When the regional aquifer is first encountered, a static water level shall be measured by the FTL, using a dedicated water-level meter and/or a pressure transducer system.	Water level measurements were obtained during drilling using a water-level meter.
Field Hydraulic-Property Tests	Not specified in hydrogeologic work plan	The hydrology task leader shall design and conduct slug or pumping tests once the well is completed.	None conducted

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Surface Casing	Approximately 20-in. OD, extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	18-in.-OD steel casing will be installed and cemented in place to isolate the borehole from surface water and possible alluvial groundwater and to stabilize the upper part of the borehole from caving and collapse.	18-in.-OD steel casing set at 23 ft bgs and cemented in place.
Minimum Well Casing Size	6.625-in.-OD	5-in-OD by 4.5-in.-ID	5.5-in.-OD (4.5-in-ID) stainless steel casing w/ external couplings.
Well Screen	Machine-slotted (0.01-in.) stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED	Well screen shall be constructed with multiple sections of 5.56-in OD pipe based stainless-steel screen, with a 0.010-in slot size	Screened intervals constructed of 5.56-in OD (4.5-in ID) pipe based, stainless steel, wire wrapped, 0.010-in slotted screen.
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Primary filter pack shall consist of round, clean, washed and resieved silica sand with a uniformity coefficient of 2.0 or less, placed 10 ft above and 5 ft below the well screen. The size of the filter pack shall be selected based on the characteristics of the formation to be screened. Secondary filter pack is finer, clean, washed silica sand emplaced a minimum of 2 ft below and above the primary pack.	Screen 1: Primary filter pack consists of 6.5 ft of 20/40 sand below screen, 20/40 sand and 6/9 sand (50/50 mix) across screen and 4.3 ft of 20/40 sand above mix. Secondary filter pack constructed of 2.1 ft of 30/70 sand above 20/40 sand. Screen 2: Primary filter pack consists of 20/40 silica sand 10.7 ft below screen and 2.1 ft up into the screen, slough across the remainder of the screen and 3.3 ft above with 5 ft of 20/40 silica sand above slough. Secondary filter pack of 30/70 silica s and constructed in a 1-ft-thick layer above and a 1.5-ft-thick layer below the primary filter pack. Screen 3: Primary filter pack constructed of 20/40 silica sand placed 1.2 ft below and 10.4 ft above screen. Secondary filter pack constructed of 5.5 ft slough below screen and 2.0 ft of 30/70 ft below slough and 1.3 ft above 20/40 sand. Screen 4: Primary filter pack constructed of 20/40 silica sand placed 3.8 ft below and 7.7 ft above the screen. No secondary filter pack.

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Backfill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump	The annular space in the blank zones between filter packs associated with screens and above the top-most secondary filter pack shall be sealed with a mixture of approximately 50% bentonite (chips or pellets) and 50% gravel or sand. As necessary, 5- to 10-ft cement plugs may be placed within the bentonite and gravel/sand intervals to provide stable floors for the placement of annular fill. The annular space fro a depth of approximately 75-ft to land surface shall be sealed with cement grout.	Bentonite pellets, bentonite chips, and bentonite chips and 6/9 or 8/12 sand mixture between filter packs. One cement grout plug and cement from surface to 73.6 ft bgs.
Sump	Stainless-steel casing, approximately 10 ft, with an end cap	A capped 30-ft section of stainless-steel casing	5.0-in diameter stainless-steel casing 20 ft long
Bottom Seal	Bentonite	Bentonite	No bottom seal constructed due to sloughing and unstable formation at the bottom of the borehole.

Appendix B

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qal, Alluvium	Unconsoilidated sediments, grayish-orange (10YR 7/4) to yellowish-gray (5YR 8/1), pumiceous, vitric. +10F: upper 1 ft consists of poorly developed soil; remainder made up of glassy to sugar-textured pumice (0.5 to 1.0 cm), minor quartz and sanidine crystals, rare dacite lithics; trace clay.	0–20	6472.6–6452.6
Qbog, Guaje Pumice Bed	Tephra deposit, yellowish-gray (5YR 8/1), pumiceous, vitric, nonwelded. +10F: (i.e., plus No.10 sieve sample fraction) 98–99% coarse pumice fragments (0.5 to 3.0 cm) that are uniformly vitric, 1–2% dacite lithics.	20–25	6452.6–6447.6
	Tephra deposit, grayish-orange (10YR 7/4) pumiceous, vitric, nonwelded. +10F: 99% glassy pumice (0.5 to 1.0 cm), fragments rounded with local rinds of clay; very slight local Fe-oxide staining; trace dacite lithics.	25–35	6447.6–6437.6
Tpf, Puye Formation	No sample collected. Basal Qbog contact with underlying Tpf estimated at 35 ft bgs.	35–36	6437.6–6436.6
	Volcaniclastic sediments, gravel (GW) with sand, light brown (5YR 4/1), coarse pebbles (up to 4.0 cm) are angular to subrounded. +10F: clasts composed of 80–95% dacite and hornblende-dacite; 5–20% andesite, basalt, and vitrophyre; matrix of silty sand, sanidine, quartz, and mafic minerals.	36–46	6436.6–6426.6
	Volcaniclastic sediments, silty sandy gravel (GM), light brownish-gray (5YR 6/1), pebbles (0.5–3.0 cm) mostly subrounded. +10F: clasts composed of 98% light and dark gray hornblende-dacite, pinkish dacite, slight Fe-oxide staining; 2% other volcanic lithics, sanidine, and quartz crystals.	46–61	6426.6–6411.6
	Volcaniclastic sediments, silty sandy gravel (GM), grayish-orange (10YR 7/4), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of 95–98% light gray pyroxene- and hornblende-bearing dacites, clasts commonly have clay coatings; 2–5% pumice, quartz, sanidine and mafic minerals.	61–71	6411.6–6401.6
	Clastic sediments (30% by volume) represented by silty, sandy gravel (GM), grayish-orange (10YR 7/4), pebbles (up to 2.0 cm) are subrounded made up mostly of subrounded clasts porphyritic dacite. Remaining 70% of +10F sample consists of broken fragments of vesicular, oxidized basalt with abundant amygdaloidal clay. Basal Tpf contact with underlying Tb4 lava is estimated at approximately 76 ft bgs.	71–76	6401.6–6396.6
Tb 4, Cerros del Rio Basalt	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular. WR/+10F: 85–90% broken fragments of oxidized, vesicular basalt, abundant clay-filled vesicles; 10–15% rounded granules of dacitic volcanics.	76–81	6396.6–6391.6
	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular to scoriaceous, altered. WR/+10F: 95–98% broken fragments of oxidized, vesicular and scoriaceous basalt, abundant clay-filled vesicles; trace dacitic volcanics and siltstone.	81–91	6391.6–6381.6
	Basalt, medium-dark gray (N4), vesicular. WR/+10F: 95–98% broken fragments of vesicular basalt, slight oxidation, minor clay in vesicles; 2–5% tan-colored siltstone fragments.	91–101	6381.6–6371.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb 4, Cerros del Rio Basalt	Basalt, medium-dark gray (N4), vesicular. WR/+10F: 100% broken fragments of vesicular basalt, slight oxidation, moderate to abundant white clay in vesicles.	101–111	6371.6–6361.6
	Basalt, medium-dark gray (N4), fine-grained, slightly vesicular. WR/+10F: 98–99% broken fragments fine-grained basalt, moderate to abundant clay; 1–2% siltstone.	111–121	6361.6–6351.6
	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular, fine-grained. WR/+10F: 95–98% broken fragments fine-grained basalt, slightly oxidized, moderate amygdaloidal clay; 3–5% fragments of pale tan colored clay and siltstone.	121–132	6351.6–6340.6
	Basalt, medium-dark gray (N4), massive, fine grained. WR/+10F: 100% broken fragments fine-grained basalt, slightly porphyritic with aphanitic groundmass, olivine phenocrysts up to 2 mm, minor Fe-oxides and clay.	132–142	6340.6–6330.6
	Basalt, medium-dark (N4) to dark gray (N3), highly vesicular, slightly porphyritic with fine-grained groundmass. WR/+10F: 97% broken chips of fine-grained olivine basalt, Fe-oxides and clay coatings on fragments, locally reddish (oxidized) coloration; 2–3% siltstone and/or clay fragments.	142–147	6330.6–6325.6
	Basalt, dark gray (N3) to locally dark reddish-brown (10R 3/4), vesicular to scoriaceous, slightly porphyritic with fine-grained groundmass. WR/+10F: 75% broken chips of fine-grained olivine basalt, highly oxidized, moderate white to tannish clay coatings on fragments; 20–25% glassy black scoria commonly with bluish silica veinlets or coatings; 2–3% siltstone or clay fragments. +35F: (i.e., plus No. 35 sieve sample fraction) 65% vitric scoriaceous basalt. Basal Tb4 contact with underlying Tpf estimated at 152 ft bgs.	147–152	6325.6–6320.6
Tpf, Puye Formation	Volcaniclastic sediments, silty sandy gravel (GM), dark yellowish-brown (10YR 4/2), pebbles (up to 1.5 cm) mostly subangular. +10F: 100% dacitic lithic clasts that are subangular; trace clay.	152–157	6320.6–6315.6
	Volcaniclastic sediments, sand (SW) with gravel and clay, dark yellowish-brown (10YR 4/2), pebbles (up to 0.5 cm) are angular. +10F: 100% lithic clasts made up of light gray to pinkish hornblende-biotite dacite.	157–162	6315.6–6310.6
	Volcaniclastic sediments, silty sandy gravel (GM), pale yellowish-brown (10YR 6/2), angular to subangular pebbles (up to 2.0 cm). +10F: 98–99% clasts made up of light gray to pinkish hornblende- and biotite-dacites; 1–2% clasts of vitric dacite, variolitic rhyodacite, and latite.	162–172	6310.6–6300.6
	Volcaniclastic sediments, sandy gravel (GW) with clay, medium-light gray (N6), subrounded pebbles (up to 2.0 cm). +10F: 100% lithic clasts made up of light gray hornblende- and pyroxene-bearing dacites.	172–177	6300.6–6295.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GW) with sand and clay, medium gray (N5), subangular to subrounded pebbles (up to 1.3 cm). +10F: 100% lithic clasts made up of light gray porphyritic dacites; dacites locally glassy, sugary surface texture at 177–182 ft bgs.	177–192	6295.6–6280.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), subangular to subrounded pebbles (up to 1.3 cm). +10F: 100% lithic clasts made up of light gray porphyritic dacites, locally quartz-bearing dacite.	192–202	6280.6–6270.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), coarse subangular to subrounded pebbles (up to 3.0 cm). +10F: 100% lithic clasts made up of mixed reddish and light-gray hornblende-bearing dacite and other porphyritic dacites.	202–212	6270.6–6260.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), coarse subangular to subrounded pebbles (up to 3.0 cm). +10F: 100% clasts of mixed reddish, tan, and light-gray hornblende-bearing dacites, trace quartzite present.	212–222	6260.6–6250.6
	Volcaniclastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), subangular to subrounded pebbles (up to 1.0 cm). +10F: 100% lithic clasts made up of mixed pinkish and light-gray hornblende-bearing dacites.	222–232	6250.6–6240.6
	Volcaniclastic sediments, gravel (GW) with silt and sand, grayish-orange pink (5YR 7/2), subangular to subrounded pebbles (up to 1.0 cm). +10F: 95–97% mixed clasts of pinkish, light-gray, and bleached hornblende-, biotite-, and quartz-bearing dacites, local clay and calcium carbonate coatings; 3–5% clasts of volcaniclastic sandstone.	232–242	6240.6–6230.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.0 cm). +10F: 95–99% mixed clasts of light gray and bleached hornblende- and biotite-bearing dacites; 1–3% clasts of volcaniclastic sandstone, quartz grains.	242–252	6230.6–6220.6
	Volcaniclastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 2.0 cm). +10F: 100% mixed light gray and bleached hornblende- and quartz-bearing dacites.	252–257	6220.6–6215.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.8 cm). +10F: 100% mixed dacite clasts including light gray and bleached biotite-, hornblende-bearing dacites; trace quartzite.	257–277	6215.6–6195.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% mixed dacite clasts that are generally bleached, including biotite- and hornblende-bearing dacites.	277–287	6195.6–6185.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6), angular to subrounded pebbles (up to 1.0 cm). +10F: 100% mixed dacite clasts that are generally bleached, including biotite- and hornblende-bearing dacites.	287–292	6185.6–6180.6
	Volcaniclastic sediments, silty gravel (GM) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.0 cm). +10F: 100% monolithologic light gray dacite clasts that are generally bleached.	292–302	6180.6–6170.6
	Volcaniclastic sediments, gravel (GW) with silt and sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% monolithologic light gray to bleached dacite clasts; trace quartzites.	302–312	6170.6–6160.6
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.0 cm). +10F: 100% monolithologic light gray to bleached dacite clasts; trace grains of quartz.	312–317	6160.6–6155.6
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% mixed porphyritic dacite clasts including light gray, reddish, and bleached; trace grains of quartz.	317–327	6155.6–6145.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), angular to rounded pebbles (up to 1.5 cm). +10F: 90–95% mixed light gray and pinkish dacites; 5–10% rounded quartzite and meta-granitic clasts. Note: first appearance of significant percentages of Precambrian lithologies denotes the stratigraphic top of axial river gravels within the Puye Formation in the interval 327 to 402 ft bgs.	327–332	6145.6–6140.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.5 cm). +10F: 80–85% mixed light gray and pinkish dacites; 15–20% rounded quartzite, metamorphic rocks, and pink potash feldspar (microcline).	332–342	6140.6–6130.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.5 cm). +10F: 93–95% mixed light gray and pinkish dacite clasts; 5–7% rounded quartzite, pink microcline, and granitic clasts.	342–357	6130.6–6115.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.0 cm). +10F: 85% mixed dacite and silicified dacites; 15% rounded quartzite and meta-granitic clasts.	357–362	6115.6–6110.6
	Clastic sediments, silty gravel with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 95–97% mixed variety of dacite, flow-banded rhyodacite, and silicified dacites; 3–5% rounded quartzite and meta-granitic clasts.	362–372	6110.6–6100.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 80–85% mixed light gray and bleached dacites; 10–15% rounded quartzite and Precambrian granite clasts. Note: significant reduction in percentage of Precambrian clasts below 377 ft bgs.	372–377	6100.6–6095.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 0.5 cm). +10F: 100% mixed varieties of light gray fresh dacite and earthy-textured, clay-altered bleached dacite; trace pumice.	377–382	6095.6–6090.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subangular to subrounded pebbles (up to 2.0 cm). +10F: 98% mixed varieties of dacite; 2% clay-altered vesicular basalt, andesite and earthy-textured, clay-altered bleached dacite. +35F: contains trace pumice.	382–387	6090.6–6085.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.0 cm). +10F: 97–99% mixed varieties of light gray, pink, and white (bleached) dacite; 1–3% quartzites. +35F: contains 10–15% clay-altered pumices in the interval 292 to 297 ft bgs.	387–397	6085.6–6075.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 95% mixed light gray and bleached dacite; 3–5% quartzites. +35F: contains 10–15% clay-altered pumices. Note: the interval 402 to 534 contains significant amounts of pumice with interspersed lenses of river gravel.	397–402	6075.6–6070.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 50–85% mixed pinkish and gray dacites; 15–30% white altered pumice; up to 20% pumiceous clay-cemented sandstone. +35F: contains >50% clay-altered pumices.	402–412	6070.6–6060.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 15% mixed dacites; 30% white altered (waxy luster) pumice; up to 55% pumiceous clay-cemented sandstone; 1–2% quartzite.	412–417	6060.6–6055.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 60–70% mixed light gray and bleached dacites; 5–10% white altered hornblende-bearing pumice; 20–25% pumiceous clay-cemented sandstone; 1–2% quartzite.	417–422	6055.6–6050.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites and white altered pumice; 1–2% quartzite. +35F: contains 10% pumice.	422–432	6050.6–6040.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites; 5% white altered pumice; <1% quartzite and plutonic lithologies.	432–442	6040.6–6030.6
	Clastic sediments, gravel (GW) with silt and sand, light gray (N6), angular to subrounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites; minor pumiceous sandstone; trace quartzite.	442–447	6030.6–6025.6
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to rounded pebbles (up to 2.0 cm). +10F: mostly mixed dacites; minor pumiceous sandstone; 1–2% quartzite and plutonic rocks.	447–452	6025.6–6020.6
	Clastic sediments, gravel (GW) with sand and silt, light brownish-gray (5YR 6/1), angular to rounded pebbles (up to 2.5 cm). +10F: mostly mixed dacites; minor hornblende-bearing pumice; 2% quartzite and plutonic rocks.	452–462	6020.6–6010.6
	Clastic sediments, silty gravel (GM) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.2 cm). +10F: 90% mixed dacites; 2–4% pumice; 4–5% quartzite and plutonic rocks.	462–472	6010.6–6000.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to subrounded pebbles (up to 2.5 cm). +10F: dominantly mixed varieties of dacite; 10% amphibole-bearing pumice; 10% quartzite. +35F: contains 5% pumice.	472–477	6000.6–5995.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to subrounded pebbles (up to 2.5 cm). +10F: dominantly mixed varieties of dacite; 30% pumice; 1% quartzite. +35F: contains 60% pumice.	477–482	5995.6–5990.6
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), angular to subrounded pebbles (up to 1.0 cm). +10F: dominantly mixed varieties of dacite and pumiceous clay-cemented sandstone; 1% quartzite. +35F: contains 40% pumice.	482–487	5990.6–5985.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to rounded pebbles (up to 2.0 cm). +10F: dominantly mixed varieties of dacite; 5% quartzite; some carbonate nodules (up to 1.0 cm). +35F: contains 20% pumice.	487–492	5985.6–5980.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), angular to subrounded clasts. +10F: 80–95% pumice and clay-cemented pumiceous sandstone; 15–20% dacite clasts. +35F: contains 10–50% amphibole-bearing pumice.	492–507	5980.6–5965.6
	Clastic sediments, gravel (GW) with clay and sand, grayish-orange pink (5YR 7/2), angular to subrounded clasts (up to 2.0 cm). +10F: dominantly mixed varieties of dacite; 10% quartzite. +35F: contains 10% pumice.	507–512	5965.6–5960.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, silty sand with gravel (SM), pale yellowish-brown (10YR 6/2), angular to subangular clasts (up to 2.2 cm). +10F: dominantly dacite and silicified dacite; 1–3% quartzite. +35F: contains 10–60% pumice.	512–527	5960.6–5945.6
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded clasts (up to 1.7 cm). +10F: mostly dacite clasts, lesser amounts of pumice, 10% quartzite clasts. +35F: contains 5% pumice.	527–532	5945.6–5940.6
	Transitional Tpf/Tb2 interval. Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded clasts (up to 1.7 cm). +10F: 30–35% dacite volcanic clasts; 65–70% altered basalt fragments; 3–5% quartzite clasts. Basal Tpf contact with underlying Tb2 estimated at 534 ft bgs	532–537	5940.6–5935.6
Tb 2, Santa Fe Group Basalt	Basalt, light brownish-gray (5Y 6/1), altered. +10F: highly altered basalt fragments; trace quartzite.	537–542	5935.6–5930.6
	Basalt, pale yellowish-brown (10YR 6/2), microcrystalline. +10F: fragments highly altered. +35F: contains abundant quartz sand (probably slough).	542–547	5930.6–5925.6
	Basalt, pale yellowish-brown (10YR 6/2), microcrystalline. +10F: 90% fine-grained basalt fragments that are highly altered and with green clay alteration. +35F: contains 50% pumice fragments (probably slough).	547–552	5925.6–5920.6
	Basalt, light olive-gray (5YR 6/1), microcrystalline, massive. +10F: fine-grained basalt fragments that are highly altered.	552–562	5920.6–5910.6
	Basalt, medium-dark gray (N4), microcrystalline, massive. +10F: fine-grained basalt, slightly vesicular.	562–570	5910.6–5902.6
	Basalt, pale brown (5YR 5/2), microcrystalline. +10F: fine-grained basalt scoria.	570–575	5902.6–5897.6
	Basalt, pale brown (5YR 6/2) to medium-dark gray (5G 4/1), porphyritic with aphanitic groundmass, vesicular. +10F: olivine phenocrysts mostly altered to iddingsite.	575–585	5897.6–5887.6
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: phenocrysts of olivine, plagioclase, and pyroxene; olivines partly altered or replaced by iddingsite; some calcite in-filling of vesicles.	585–595	5887.6–5877.6
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: olivines partly altered or replaced by iddingsite; some calcite in-filling of vesicles; yellowish clay present at 605–610 ft bgs.	595–610	5877.6–5862.6
	Basalt, reddish-brown (5YR 5/4), porphyritic with aphanitic groundmass, scoriaceous. +10F: basaltic scoria; olivines replaced by bright red-orange iddingsite, pyroxene and feldspar phenocrysts generally unaltered; groundmass moderately to highly altered; calcite filling vesicles common; orange-red clay present. WR sample clay rich.	610–615	5862.6–5857.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb 2, Santa Fe Group Basalt	Basalt, dark gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: altered phenocrysts of olivine, pyroxene, and plagioclase; white silica on some fractures; abundant calcite filling vugs and vesicles. WR sample clay rich.	615–625	5857.6–5847.6
	Basalt, gray (N6), porphyritic with aphanitic groundmass, vesicular. +10F: altered phenocrysts of olivine are yellow-brown with dark rinds; pyroxene and plagioclase phenocrysts mostly altered; calcite filling vugs and vesicles common.	625–635	5847.6–5837.6
	Basalt, greenish-black (5GY 2/1), porphyritic with aphanitic groundmass, massive. +10F: altered phenocrysts of olivine, pyroxene, and plagioclase; greenish powdery mineral locally lining vugs and vesicles.	635–650	5837.6–5822.6
	Basalt, greenish-black (5GY 2/1), porphyritic with aphanitic groundmass, massive. +10F: altered phenocrysts of olivine replaced by honey-colored iddingsite; pyroxene and plagioclase phenocrysts moderately fresh.	650–665	5822.6–5807.6
	Basalt, pale yellowish-brown (10YR 6/2) to moderate orange-pink (10r 7/4), porphyritic with aphanitic groundmass, scoriaceous. +10F: basalt scoria and cinders marking the base of Tb2; vesicles in-filled with calcite, white powdery mineral, and red-orange clay.	665–670	5807.6–5802.6
Tsf, Santa Fe Group Sediments	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2), fine to very coarse sand, angular to rounded grains. +10F: sand grains of basalt, quartz, and pumice; clay-cemented orange fragments present.	670–675	5802.6–5797.6
	Clastic sediments, clayey sand (SC), pale yellowish-brown (10YR 6/2), mostly coarse-grained sand in a clayey matrix, subrounded to rounded grains. +10F: sand grains of quartz with lesser amounts of basalt and pumice; gray and orange clay present.	675–680	5797.6–5792.6
	Clastic sediments, sand (SW) with clay and gravel (SW), grayish-orange pink (5YR 7/2), fine to coarse-grained sand and gravel (up to 1.0 cm), subrounded grains. +10F: gravel clasts of dacite, pumice, basalt, quartz.	680–685	5792.6–5787.6
	Clastic sediments, sand (SW) with clay, grayish-orange pink (5YR 7/2), clay to coarse sand grains that are subrounded. +10F: grains composed of dacite quartz, and pumice, commonly clay-cemented.	685–690	5787.6–5782.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), rounded pebbles (up to 2.0 cm). +10F: clasts composed of dacite, quartz, pumice, and clay-cemented sandstone.	690–695	5782.6–5777.6
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +10F: sand grains composed of dacite, quartz, basalt, and clay-cemented sandstone.	695–700	5777.6–5772.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, sand (SW) with gravel, grayish-orange pink (5YR 7/2), pebbles (up to 2.2 cm) are subrounded to rounded. +10F: clasts composed of dacite, silicified dacite, plus minor quartz and basalt.	700–705	5772.6–5767.6
	Clastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of abundant intermediate volcanics (dacite, silicified dacite) and clay-cemented sandstone.	705–715	5767.6–5757.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of a variety of volcanic rocks (andesite, basalt, pumice) and minor quartzite; earth-brown clay fragments present.	715–720	5757.6–5752.6
Tb 2, Santa Fe Group Basalt	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, slightly vesicular, highly altered. +10F: altered phenocrysts of olivine (red orange iddingsite) and plagioclase; vesicles commonly filled with calcite, zeolite, and Mn-oxides. WR sample clay rich.	720–735	5752.6–5737.6
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, massive, slightly altered. +10F: phenocrysts of olivine (greenish iddingsite); calcite on some fracture surfaces.	735–745	5737.6–5727.6
	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, massive to vesicular, moderately altered. +10F: massive and vesicular basalt present, phenocrysts of olivine (reddish iddingsite); calcite, clay, and zeolite on fracture surfaces and filling vesicles; groundmass feldspars argillized.	745–755	5727.6–5717.6
	Basalt, medium gray (N4) to dark gray (N3), porphyritic with aphanitic groundmass, massive, moderately altered. +10F: olivine phenocrysts replaced by reddish iddingsite; alteration includes calcite, clay, and chlorite on fracture surfaces and filling vesicles; some clay-cemented fine sandstone and quartz sand present.	755–765	5717.6–5707.6
	Basalt, medium gray (N4) to dark gray (N3), porphyritic with aphanitic groundmass, massive to vesicular, moderately altered. +10F: massive and vesicular basalt present, ferromagnesian phenocrysts are oxidized, feldspar phenocrysts argillized; groundmass affected by sericite-chlorite and calcite alteration.	765–785	5707.6–5687.6
	Transitional Tb2/Tsf interval. Light gray (N6) basalt and pale brown (5YR 7/2) volcaniclastic sediments. +10F: 5–10% basalt, highly altered, some pale bluish chalcedony filling vesicles; 90–95% rounded, highly altered volcaniclastic gravel and clay-cemented sand.	785–790	5687.6–5682.6
	Basalt, medium gray (N4) to light gray (N5), porphyritic with aphanitic groundmass, vesicular, highly altered. +10F: ferromagnesian phenocrysts are oxidized with distinctive Fe-oxide rinds, feldspar phenocrysts argillized; amygdaloidal clay and calcite. WR sample clay rich.	790–795	5682.6–5677.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, sandy clay (CH) with gravel, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.5 cm). +10F: variety of altered, silicified volcanic lithologies, rare basalt, minor quartzite.	795–805	5677.6–5667.6
	Clastic sediments, sand (SW) with gravel and clay, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 1.5 cm). +10F: 90% volcanic lithologies of felsic to intermediate composition; 10% sandstone fragments. +35F: abundant quartz sand grains present. WR: sample clay rich.	805–815	5667.6–5657.6
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.0 cm). +10F: dominantly volcanic lithologies similar to interval 805–815 ft, abundant indurated sandstone fragments.	815–820	5657.6–5652.6
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.0 cm). +10F: dominantly volcanic lithologies similar to 805–815, abundant indurated sandstone fragments.	820–841	5652.6–5631.6
	Clastic sediments, clay (CH) with sand and gravel, grayish-orange pink (5YR 7/2), subrounded pebbles (up to 2.0 cm). +10F: dominantly intermediate and lesser felsic volcanic lithologies, local clay and Mn-oxide clasts present. +35F: fine to medium sand made up of quartz and diverse volcanic lithologies. WR sample clay-rich.	841–850	5631.6–5622.6
Tb 2, Santa Fe Group Basalt	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, vesicular to massive, highly altered. +10F: basalt is intensely altered; olivine phenocrysts are distinctively greenish in color with iddingsite rims; phenocryst and groundmass feldspars completely argillized, or vacated, resulting in a pitted and vuggy surface texture; abundant amygdaloidal calcite.	850–865	5622.6–5607.6
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, massive, highly altered. +10F: continued intense rock alteration with vuggy textured appearance; altered olivine phenocrysts pale greenish with opaque rims; small amount of rounded pebbles (up to 1.5 cm) made up of basalt and intermediate porhyritic volcanic rocks. Note: thin interlayer (1 to 2 ft thick) of volcaniclastic sediments possibly present.	865–870	5607.6–5602.6
	Basalt, dark gray (N3), slightly porphyritic with aphanitic groundmass, massive, moderately altered. +10F: rock alteration considerably diminished, groundmass minerals distinguishable. WR sample clay-rich in lower 5 ft.	870–887	5602.6–5585.6
	Transitional Tb 2/Tsf interval. WR sample contains 50% basalt as described in interval 870 to 887 ft that is partly scoriaceous; 50% granules and pebbles of basalt and other diverse volcanic lithologies; clayey matrix.	887–892	5585.6–5580.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, gravel (GW) with sand, pale brown (5YR 5/2), subangular to rounded pebbles (up to 2.0 cm). +10F: 10–20% carbonate altered basalt and intermediate to felsic volcanic rocks, 80–90% fragments of indurated fine-grained sandstone. Basal Tb 2 contact with underlying Tsf sediments estimated at 893 ft bgs.	892–897	5580.6–5575.6
	Clastic sediments, clayey sand (SC) with gravel, pale brown (5YR 5/2), subrounded pebbles (up to 2.0 cm). +10F: pebbles of indurated fine-grained sandstone and of a variety to intermediate to felsic volcanic rocks. +35F: contains abundant volcanic rocks and frosted sand grains of quartz and quartzite.	897–902	5575.6–5570.6
R-5 BOREHOLE COMPLETED AT 902 FT BGS TOTAL DEPTH (TD)			

Notes:

1. American Society for Testing and Materials ([ASTM] D 2488-90. Standard Practice and Identification of Soils [Visual-Manual Procedure]) standards were used in describing the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following is a glossary of standard USCS symbols used in the R-5 lithologic log:.

SW = Well-graded sand	SM = Silty gravel	CH = Clay, high plasticity
GW = Well-graded gravel	GM = Silty gravel	SC = Clayey sand
GP = Poorly graded gravel	GC = Clayey gravel	

2. Cuttings at R-5 were collected from ground surface to 902 ft bgs at nominal 5-ft intervals. Each sample was divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).
3. The term *percent,* as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from “The Geological Society of America Rock-Color Chart.”

Appendix C

LANL Borehole Video Log
(CD attached to inside back cover)

Appendix D

Schlumberger Geophysical Report and Montage
(CD attached to inside back cover)

Appendix E

Westbay™ Multi-Level Sampling Diagram
(CD attached to inside back cover)